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RECOMMENDATIONS ON THE PIPELINE DIAMETER SELECTION OF CARBON DIOXIDE FIRE EXTINGUISHING SYSTEMS

(presented by DSc Abramov Y.)

A numerical solution of the flow equation is obtained, applied to pipelines of carbon dioxide extinguishing systems. Graphic dependencies of the pipeline diameter of the gas fire extinguishing system on the consumption of the extinguishing agent, the length of the pipeline and the pressure are constructed. Recommendations are given on the pipeline diameter selection for the centralized and local storage of the extinguishing agent.

Keywords: automatic gas fire extinguishing system, carbon dioxide, distribution network, pipeline diameter.

Problem formulation. The appearance of emergency at sites, in particular fires, lead to the death of people. Therefore, the issues of fire safety are constantly monitored not only by the employees of the State Emergency Service of Ukraine, but also by the government. To detect and extinguish fires at an early stage, automatic fire extinguishing systems using various extinguishing agents (FEA) are applied. The regulatory documents formulate general requirements for such systems, depending on the extinguishing method. One such system is an automatic gas fire extinguishing system (AGFES) with carbon dioxide. The effectiveness of gas systems applying in the case of volumetric fire extinguishing in enclosed spaces is considered in [1]. The functional capabilities and composition of the AGFES are presented in [2]. However, in the question of designing these systems, there is no uniform approach to the formation of distribution networks and determining the optimal pipeline diameters. Therefore, the applying of scientifically based methods for determining the parameters of networks of carbon dioxide extinguishing systems will solve the problem of increasing the reliability and efficiency of fire safety equipment and facilities.

Analysis of recent researches and publications. The issues of designing fire protection systems are devoted to the works [3, 4]. In them the problems of hydraulic calculation are considered for water extinguishing systems. In paper [5] the estimation of carbon dioxide safety on toxicity and possibility of application in various conditions is given. In work [6], a methodology for calculating the pipeline distribution network parameters of gas fire extinguishing installations based on freons was developed. In work [7] the question of gas fire extinguishing systems designing with reference to a stage of the balanced distribution network construction is considered. In this regard, it is important to develop recommendations for the selection of the pipeline network parameters of carbon dioxide fire extinguishing systems.

Statement of the problem and its solution. The purpose of the study is to formulate recommendations that will improve the design efficiency of automatic systems of carbon dioxide fire extinguishing by calculating the distribution network parameters. To achieve this goal, it is necessary to obtain dependencies that will allow estimating the pipeline diameter of the AGFES distribution network depending on the pressure, the extinguishing agent consumption and the length of the pipeline section.

When designing the AGFES, one of the stages is the calculation of the carbon dioxide mass M_{CO_2} needed to extinguish in the protected volume [7]. The time of delivery of the extinguishing agent *t* is regulated by the normative document and is 1 minute. Thus, the estimated value of the consumption of FEA can be determined from the expression

$$Q = \frac{M_{CO_2}}{t}. \tag{1}$$

On the other hand, the carbon dioxide consumption can be determined from expression [8]

$$Q^2 = \frac{0{,}8725 \cdot 10^{-5} \cdot D^{5{,}25} \cdot Y}{L + \left(0.04319 \cdot D^{1{,}25} \cdot Z\right)}, \tag{2}$$

where *D* is the distribution pipeline section diameter; *L* is the distribution pipeline section length; *Y, Z* is coefficients that depend on the pressure in the reservoir and in the pipeline, and can be found from equations:

$$Y = \int_{p_1}^{p} \rho dp;$$

$$Z = \int_{\rho_1}^{\rho} \frac{d\rho}{\rho} = \ln\frac{\rho_1}{\rho},$$

where p_1 is the pressure at which the FEA is stored, bar; *p* – is the pressure at the end of the pipeline network, bar; ρ_1 – density at pressure p_1, kg/m^{-3}; ρ – density at pressure p, kg/m^{-3}.

Knowing the flow rates for a particular section of the pipeline, determined by calculation according to formula (1), we represent expression (2) in the form

$$\left(\frac{M_{CO_2}}{t}\right)^2 \cdot L + 0{,}04319 \cdot \left(\frac{M_{CO_2}}{t}\right)^2 \cdot Z \cdot D^{1{,}25} = 0{,}8725 \cdot 10^{-5} \cdot Y \cdot D^{5{,}25}. \tag{3}$$

Rearranging the terms in (3) and introducing the notation, we pass to the nonlinear equation

$$A \cdot D^{5{,}25} - B \cdot D^{1{,}25} - C = 0, \tag{4}$$

where $A = 0{,}8725 \cdot 10^{-5} \cdot Y$; $B = 0{,}04319 \cdot \left(\frac{M_{CO_2}}{t}\right)^2 \cdot Z$; $C = \left(\frac{M_{CO_2}}{t}\right)^2 \cdot L$.

Or to an equation of the form

$$A \cdot x^{21} - B \cdot x^5 - C = 0, \quad (5)$$

where $x = D^{\frac{1}{4}}$.

Since the highest degree of the polynomial on the left-hand side of (5) is odd, the solution of this equation has at least one real root. Due to the high degree of the polynomial (5), the search for roots by analytical methods is difficult, so to solve this equation we use the numerical method. Since the left-hand side of equation (5) has derivatives up to the second order inclusive, to find the real roots of the equation we apply the Newton method [9], which is realized in the MathCAD environment.

In tabl. 1 and tabl. 2 shows the results of a numerical solution of equation (5). In Table 1 shows the values of the pipeline diameter of the carbon dioxide fire extinguishing system for the batteries of gas modules with a high exhaust FEA flow rate and remote from the protected room (modules are located in the room of the gas fire extinguishing station, that is centralized storage of the fire extinguishing agent).

In tabl. 2 presents the results typical for the local storage systems of FEA, which protect one room and fire suppression modules can be located next to the protected room.

Tabl. 1. Calculated values of pipeline diameter for centralized storage systems

Q, kg/min	Length of pipeline, m				p, bar
	10	50	80	100	
1000	59,516	70,83	88,406	92,243	51
500	45,7	62,076	67,888	80,839	
1000	40,773	54,399	59,354	61,878	45
500	31,088	41,683	45,51	47,456	
1000	37,92	50,122	54,618	56,915	40
500	28,81	38,361	41,844	43,619	
1000	36,69	48,042	52,284	54,457	35
500	27,775	36,724	40,021	41,705	
1000	36,08	46,848	50,923	53,015	30
500	27,23	35,771	38,947	40,572	
1000	35,85	46,053	49,979	52,001	25
500	26,95	35,112	38,184	39,759	
1000	36,179	45,903	49,72	51,694	20
500	27,082	34,934	37,936	39,48	
1000	36,488	45,904	49,653	51,598	17,5
500	27,234	34,891	37,85	39,375	

On fig. 1 and 2 show the dependencies that illustrate the effect of the flow rate and pressure on the pipeline diameter, with different lengths. Graphs analysis suggests that for systems with centralized storage of FEAs and for decentralized systems an insignificant change in the pipeline diameter at pressures less than 40 bar is characteristic, which is offset by the fact that in practice pipes with a diameter from the normalized range are used. However, with a large mass of FEA passing through pipelines up to 100 m in length, to reduce pressure losses, pipelines with a diameter of 60 mm, 80 mm should be used. For systems of both types, the doubling in the FEA flow rate changes the pipeline diameter by one step in the value of the conditional pass, according to the existing assortment. This conclusion makes it possible to simplify the procedure for determining the pipelines diameters of a balanced distribution network by successively decreasing the diameter of the pipe when passing through a branch (tee).

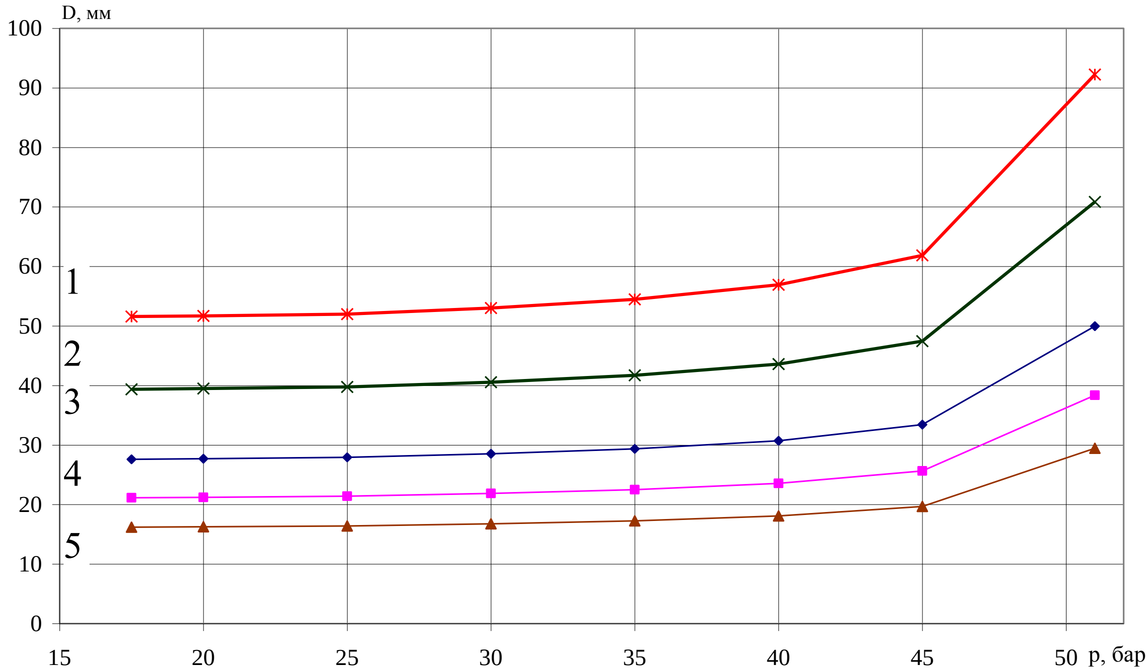

Fig. 1. Pipeline diameter dependence on pressure and FEA flow rate for a section length of 100 m: 1 – Q=1000 kg/min; 2 – Q=500 kg/min; 3 – Q=200 kg/min; 4 – Q=100 kg/min; 5 – Q=50 kg/min

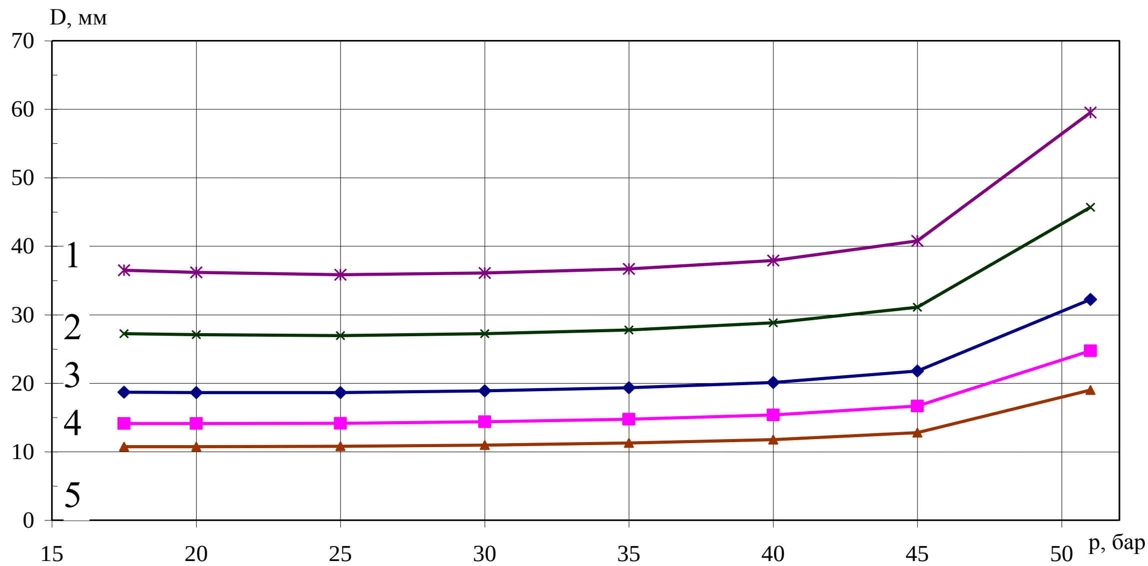

Fig.2 Pipeline diameter dependence on pressure and FEA flow rate for a section length of 10 m: 1 – Q=1000 kg/min; 2 – Q=500 kg/min; 3 – Q=200 kg/min; 4 – Q=100 kg/min; 5 – Q=50 kg/min

The dependence shown in fig. 3, can be used to select the diameter of the distribution pipeline located in the protected area. Obviously, when choosing the pipeline diameter, first of all, it is necessary to take into account the FEA mass passing through the section, since with a change in the flow rate by 4 times, the diameter changes by 42%, and with an increase in the length of the pipeline section by 4 times, the diameter increases by less than 20%.

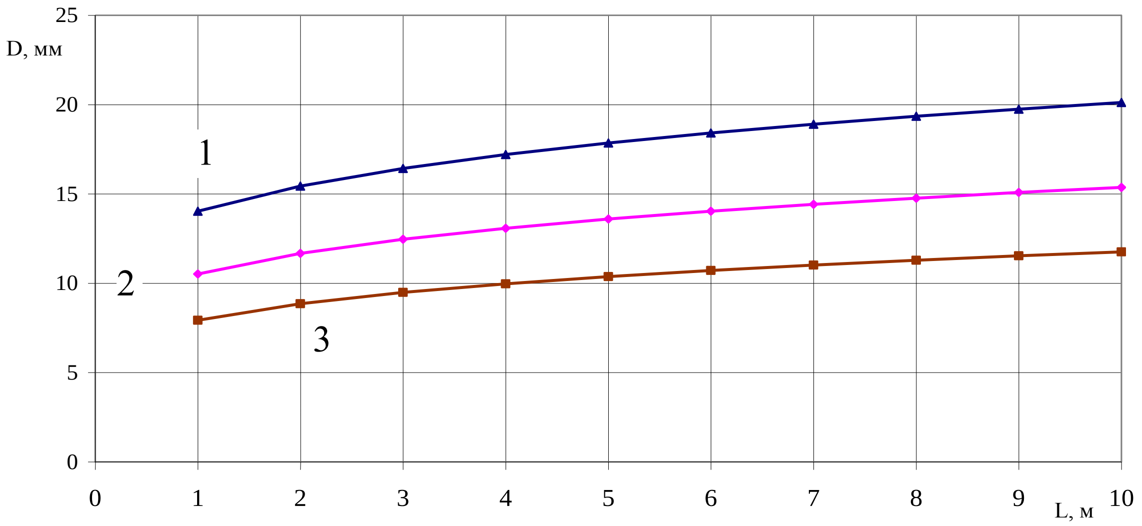

Fig. 3 Pipeline diameter dependence on the section length and flow at p=40 bar: 1 – Q=200 kg/min; 2 – Q=100 kg/min; 3 – Q=50 kg/min

The obtained dependences make it possible to determine the pipeline diameter of carbon dioxide extinguishing systems taking into account three parameters: flow rate, length and pressure. However, to fully automate the gas extinguishing system design procedure it is necessary to have formal relationships between the diameter and the remaining parameters. For example, you can use the experiment planning theory methods to process data from tables 1 and 2 and present the results in the regression models form.

Conclusions. A numerical solution of the flow equation for carbon dioxide with respect to the unknown pipeline diameter is obtained. Полученный массив данных представлен в виде графических зависимостей диаметра трубопровода от расхода ОТВ, давления и длины трубопровода. The obtained data array is presented in the graphs of the pipeline diameter on the FEA flow rate, pressure and pipeline length. Даны рекомендации по выбору диаметра подводящего и распределительного трубопровода для систем с локальным и централизованным хранением огнетушащего вещества. Recommendations are given on the choice of the supply and distribution pipeline diameter for systems with local and centralized extinguishing agent storage.

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Рекомендації по вибору діаметру трубопроводу систем вуглекислотного пожежогасіння

Отримано чисельне рішення рівняння потоку, стосовно трубопроводів систем вуглекислотного пожежогасіння. Побудовані графічні залежності діаметра трубопроводу систем газового пожежогасіння від витрати вогнегасної речовини, довжини трубопроводу і тиску. Надано рекомендації щодо вибору діаметру трубопроводу для систем централізованого та локального зберігання вогнегасної речовини.

Ключові слова: автоматична система газового пожежогасіння, діоксид вуглецю, розподільча мережа, діаметр трубопроводу.

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Рекомендации по выбору диаметра трубопровода систем углекислотного пожаротушения

Получено численное решение уравнения потока, применительно к трубопроводам систем углекислотного пожаротушения. Построены графические зависимости диаметра трубопровода системы газового пожаротушения от расхода огнетушащего вещества, длины трубопровода и давления. Даны рекомендации по выбору диаметра трубопровода для систем централизованного и локального хранения огнетушащего вещества.

Ключевые слова: автоматическая система газового пожаротушения, диоксид углерода, распределительная сеть, диаметр трубопровода.